Flow Over Difficult Bathymetry: Processes and Parameterizations

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LONG-TERM GOALS

To understand the physics of flows generated by currents passing over small topographic features and to quantify, and parameterize if possible, the mixing these flows produce.

OBJECTIVES

- To synthesize emerging measurements and numerical simulations of flow and mixing over rough topography to assess their global importance.
- To understand the physics controlling exchanges of momentum, heat, and salt between boundary layers over continental slopes and the ocean's interior.
- To use laboratory and numerical results to design experiments to illuminate crucial aspects of flow and mixing over rough topography.

APPROACH

To quantify turbulence in bottom boundary layers, Gregg and Matthew Alford (Gregg's first SECNAV post-doc who is now a staff member at the Applied Physics Laboratory) joined the 1999 Suisun Cutoff experiment, which seeks the most complete accounting of an energy budget yet attempted in a tidally-driven bottom boundary layer.

To understand the role of rough topography in converting energy from the surface tide to internal tides and mixing, Gregg and Alford are participating in the Hawaii Ocean Mixing Experiment and will take detailed measurements of turbulence and shear over the steep continental slopes of the Hawaiian Ridge.

Dr. Kate Edwards, P. MacCready's post-doc, and Ryan McCabe, his graduate student, are using satellite (SAR) images and boat-mounted ADCP surveys in Juan de Fuca to make detailed spatial maps of sidewall eddies. Wayne Martin, another of MacCready's graduate students, is using three years of moored ADCP data to analyze the tidal bottom boundary layer in Juan de Fuca. The net drag on the flow is a combination of the frictional boundary layer, and pressure drag on topographic obstacles due to both internal wave and eddy generation.

WORK COMPLETED

In October 1999 Gregg and his microstructure group studied the evolution of strong turbulence in Suisun Cutoff, a branch of the passages linking San Francisco Bay with the delta of the Sacramento River. They joined an on-going series of studies by Stanford University, University of California, Berkeley, and the U.S. Geological Survey to understand how strongly stratified regimes mix during different phases of tidal regimes. Gregg added direct measurements of the turbulent dissipation rate, ε, and resolved vertical overturns in the 10 m water column. The basic analysis of these data was completed and scientific analysis is beginning.

During a recent FY00 cruise in the Strait of Juan de Fuca, MacCready and his group completed a boat-mounted ADCP survey of several 1.5-km square regions over a tidal cycle.

Several efforts by Alford extended last year's analysis of internal waves and mixing in the Indonesian Throughflow and were submitted for publication.

Gregg participated in several meetings planning fieldwork for the Hawaii Ocean Mixing Experiment (HOME), which takes place from late August to early November 2000.

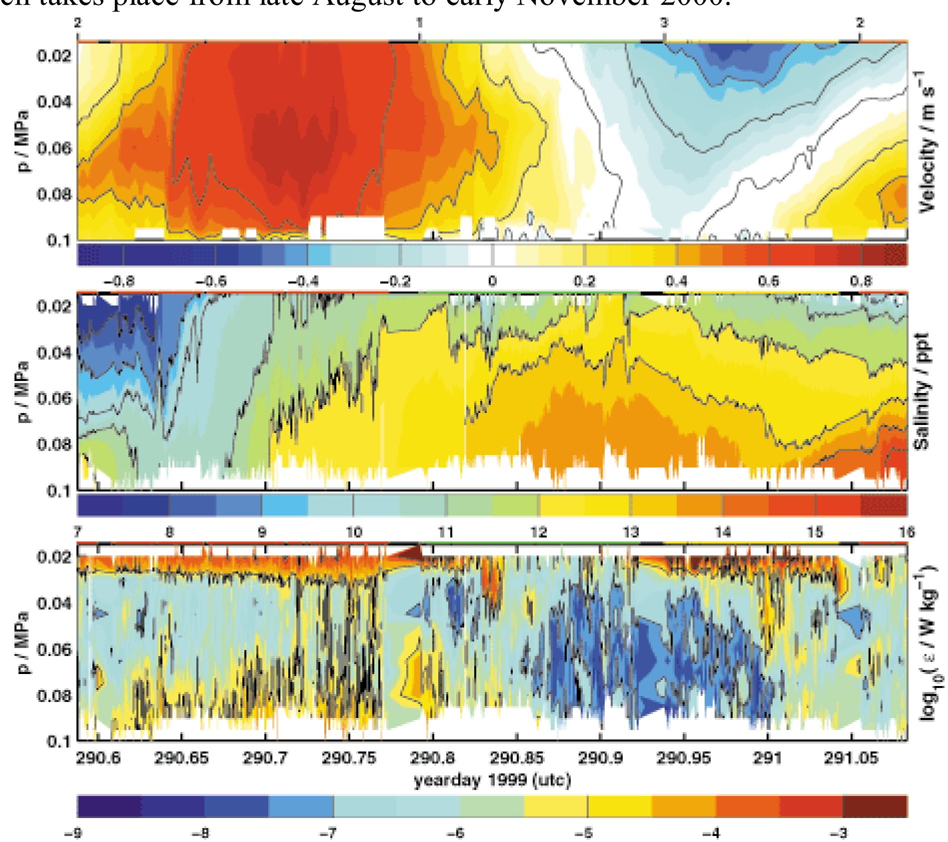

Fig. 1. Summary of one tidal cycle in Suisun Cutoff. The measurements began in the early stages of flood (positive) and ended as another flood was beginning. Flood carried saline water with it but produced little mixing above the bottom boundary layer. Owing to the weaker stratification, mixing was most intense in the middle of the water column during the weaker ebb flow, which barely extended to the bottom.

RESULTS

The observations in Suisun Cutoff recorded rapid increases and decreases of turbulence and stratifications as the tide changed. The example in Figure 1 shows the turbulence during a strong flood followed by a weak ebb. The primary mixing in the Banda Sea was produced by a strong near-inertial wave that was apparently generated by strong monsoon winds that slackened shortly before our cruise. Satellite and model wind data showed that a strong annual monsoonal mixing cycle is likely, bringing the observed and model diffusivity values much closer. These results are important since they are the first quantitative link between near-inertial waves and mixing. Since the wind is their primary source, the possibility of such annual mixing cycles in other regions is of great importance.

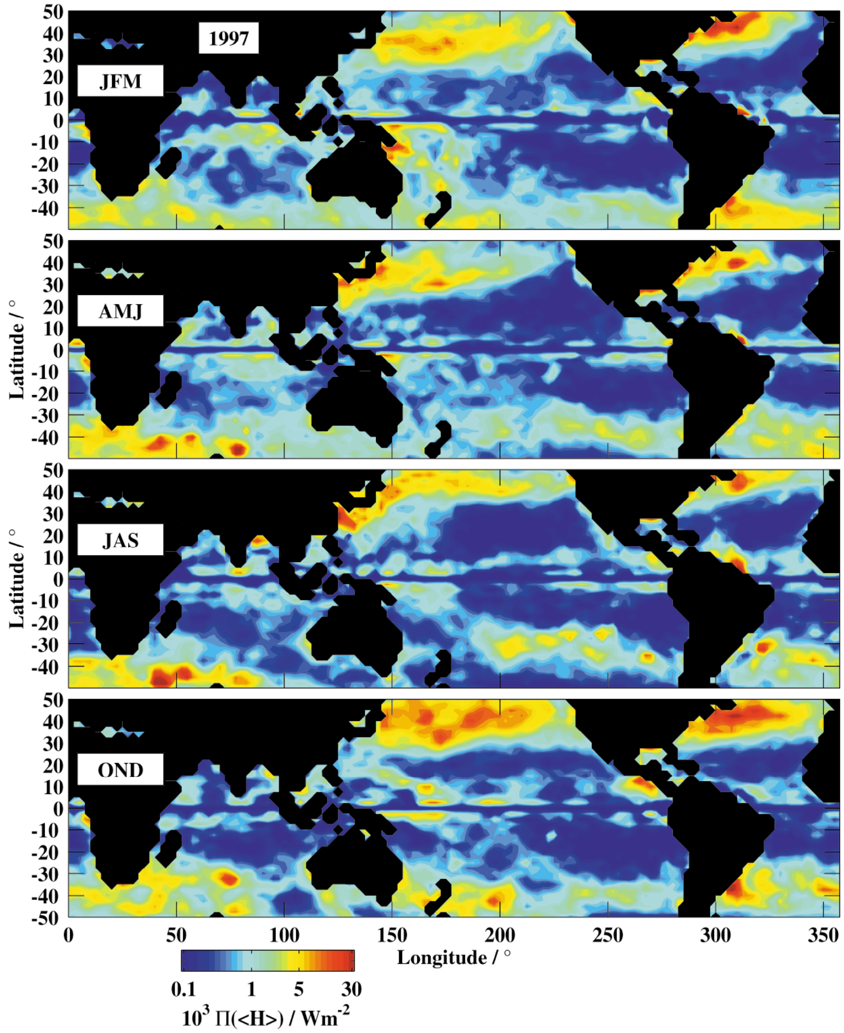

Fig. 2. Estimated energy flux into near-inertial motions from the wind for the four calendar quarters (Alford, 2000a).

This observed (local) connection between wind and mixing inspired another (global) study, partly supported by the SECNAV grant. Taking advantage of the global coverage offered by the NOAA/NCEP atmospheric model wind field, as verified against in-situ buoy wind observations, Alford (2000a) was able to extend the pioneering work of D'Asaro (1985) in order to produce global maps of the energy flux into near-inertial mixed-layer motions (Fig. 2). Since the wind and the tides are the only two power supplies for the "stirring rods" which mix the deep oceans (Munk and Wunsch, 1998), assessing the magnitude of each term is extremely important. This estimate of the wind-power input (0.29×10^{12} W, or about 10% of the 1995 human electric power capacity) is about 25% of estimates of the tidal input from TOPEX/POSEIDON data (Egbert, 1998) and from models (Sjoburg and Stigebrandt 1992, Morozov 1995).

MacCready and staff now have an analytical prediction of when stratified flow past a slope will generate internal waves. It turns out that there is an unusual (but oceanographically relevant) low-speed cutoff, which occurs when the time it takes for flow to traverse a ridge is longer than the buoyancy period divided by the slope angle. Flow below this speed (which is a function of ridge shape, stratification, and slope angle) will be almost completely horizontal. Using the 3D numerical model, we used this analytical result to successfully predict the flow regime, and then explored the nonlinear dynamics of flow past large ridges (ones with order-one isobath excursions, as is typical of many coastal regions). The numerical results gave a surprisingly simple and useful result, which is that the drag on large ridges can be parameterized with a drag coefficient of about unity, based on the projected frontal area of the ridge. This result holds for both the wave-generating regime, and for the horizontal separation regime (flow below the low speed cutoff).

IMPACT/APPLICATIONS

The work in Suisun Cutoff is expected to improve considerably the understanding of the energetics of tidal flows. This understanding is a prerequisite for improving the modeling of shallow flows.

HOME aims to examine one of two fundamental means of forcing the ocean. At the largest scale, this should show how energy gets into the deep ocean to supply the mixing that has long been inferred from indirect approaches. At smaller scales, we should extend some of the results from the Littoral Internal Waves Initiative (LIWI) to understand and hopefully parameterize mixing in beams of the internal tide emanating from shelf breaks.

The results described in MacCready's work will be a key part of a parameterization of the drag and wave generation due to flow along any rough coastal region.

RELATED PROJECTS

Hawaii Ocean Mixing Experiment (HOME) and the long-term U.S. Geological Survey study of San Francisco Bay.

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